US009427577B2

(12) **United States Patent**
Kroll et al.

(10) **Patent No.: US 9,427,577 B2**
(45) **Date of Patent: Aug. 30, 2016**

(54) **METHOD FOR DETECTING AND TREATING INSULATION LEAD-TO-HOUSING FAILURES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/453,679**

(22) Filed: **Aug. 7, 2014**

(65) **Prior Publication Data**

US 2015/0151118 A1 Jun. 4, 2015

Related U.S. Application Data

(63) Continuation of application No. 13/843,145, filed on Mar. 15, 2013, now Pat. No. 8,812,103.

(60) Provisional application No. 61/689,191, filed on Jun. 1, 2012.

(51) **Int. Cl.**
A61N 1/08 (2006.01)
A61N 1/39 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61N 1/08*** (2013.01); ***A61N 1/0563*** (2013.01); ***A61N 1/37*** (2013.01); ***A61N 1/3906*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61N 1/3925–1/3937; A61N 2001/083
See application file for complete search history.

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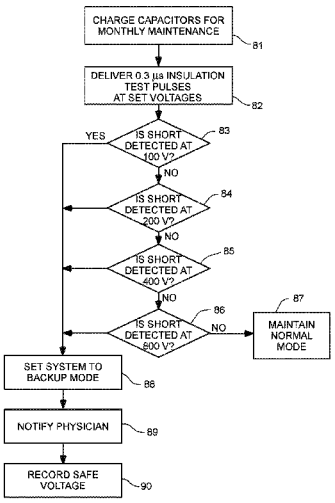
(57) **ABSTRACT**

Disclosed is a method for the diagnosis of conductor anomalies, such as an insulation failure resulting in a short circuit, in an implantable medical device, such as an implantable cardioverter defibrillator (ICD). Upon determining if a specific defibrillation pathway is shorted, the method excludes the one electrode from the defibrillation circuit, delivering defibrillation current only between functioning defibrillation electrodes. Protection can be provided against a short in the right-ventricular coil-CAN defibrillation pathway of a pectoral, transvenous ICD with a dual-coil defibrillation lead. If a short caused by an in-pocket abrasion is present, the CAN is excluded from the defibrillation circuit, delivering defibrillation current only between the right-ventricular and superior vena cava defibrillation coils. Determination that the defibrillation pathway is shorted may be made by conventional low current measurements or delivery of high current extremely short test pulses.

8 Claims, 6 Drawing Sheets



(51) **Int. Cl.**
A61N 1/37 (2006.01)
A61N 1/05 (2006.01)

(52) **U.S. Cl.**
CPC ***A61N 1/3925*** (2013.01); *A61N 1/3931* (2013.01); *A61N 1/3956* (2013.01); *A61N 2001/083* (2013.01)

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Fig. 1
Prior Art

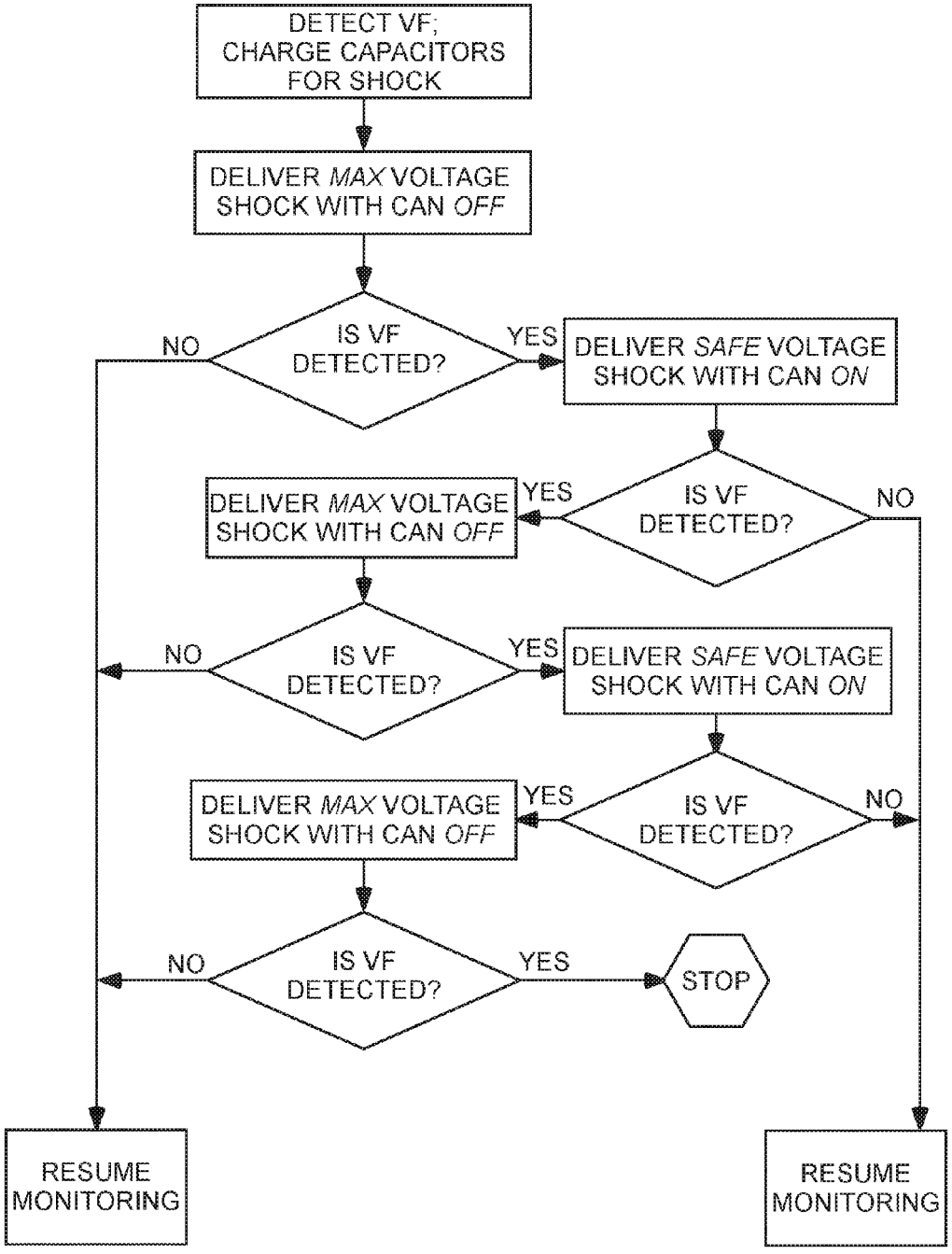


Fig. 2

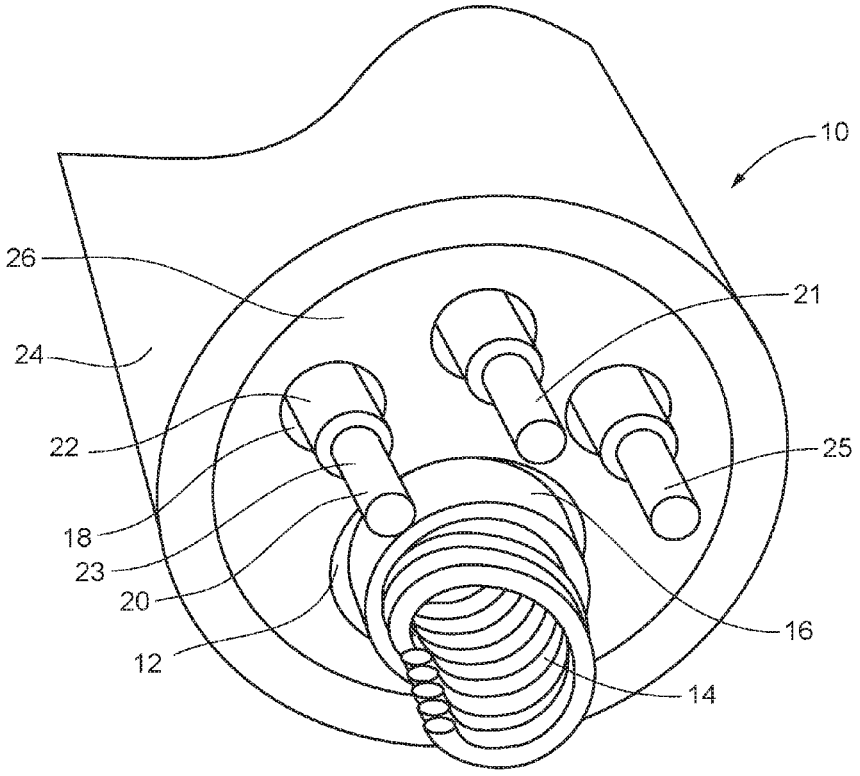


Fig. 3

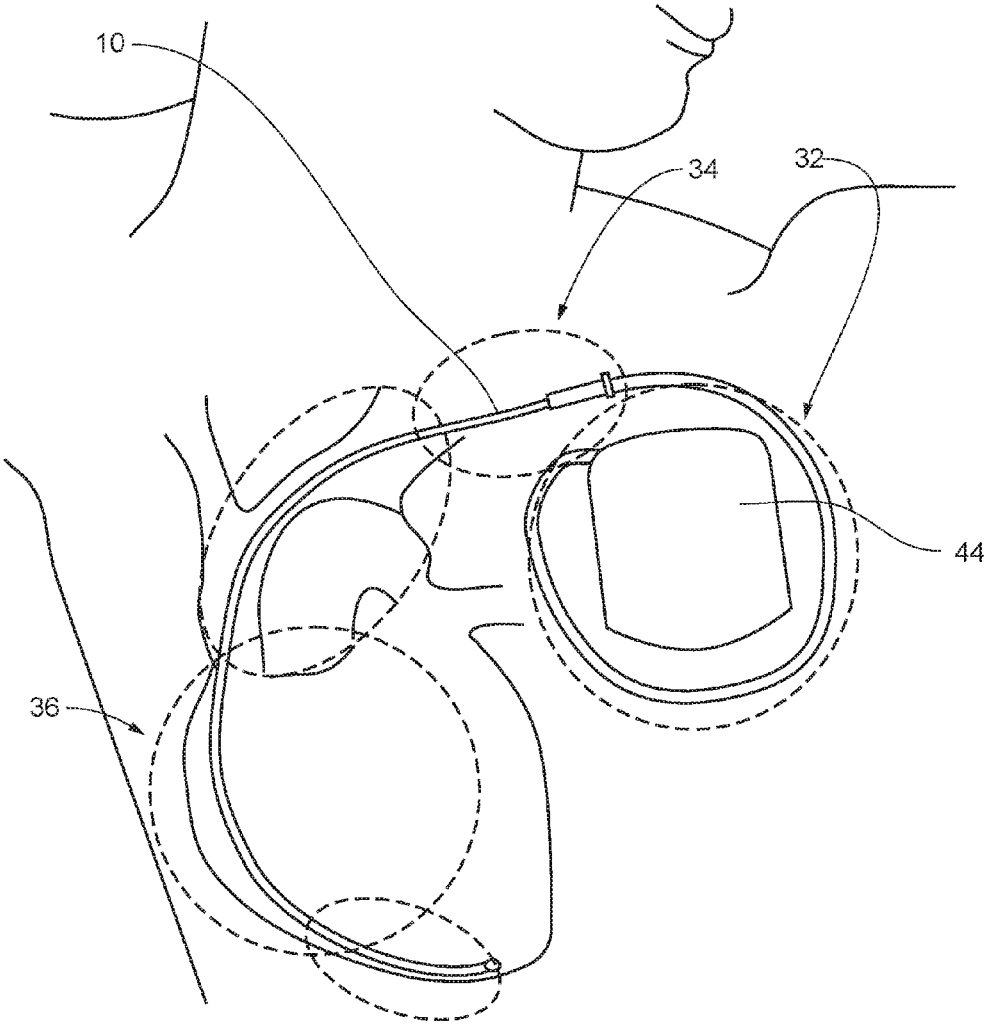


Fig. 4

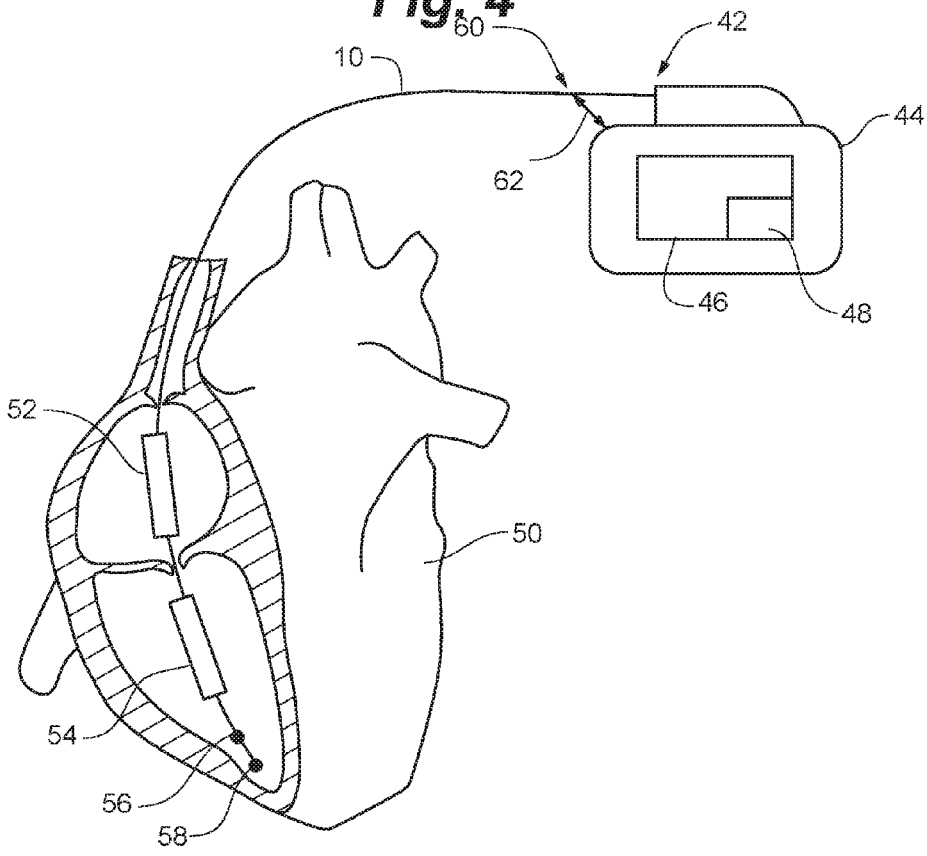


Fig. 5

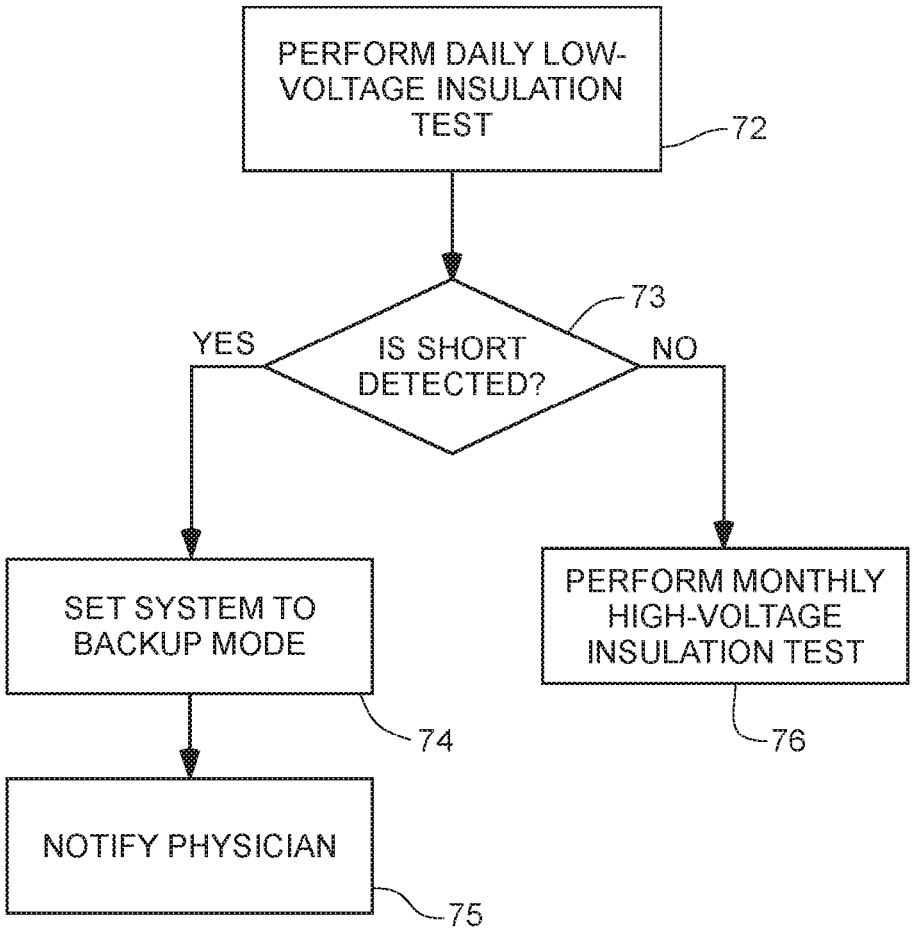
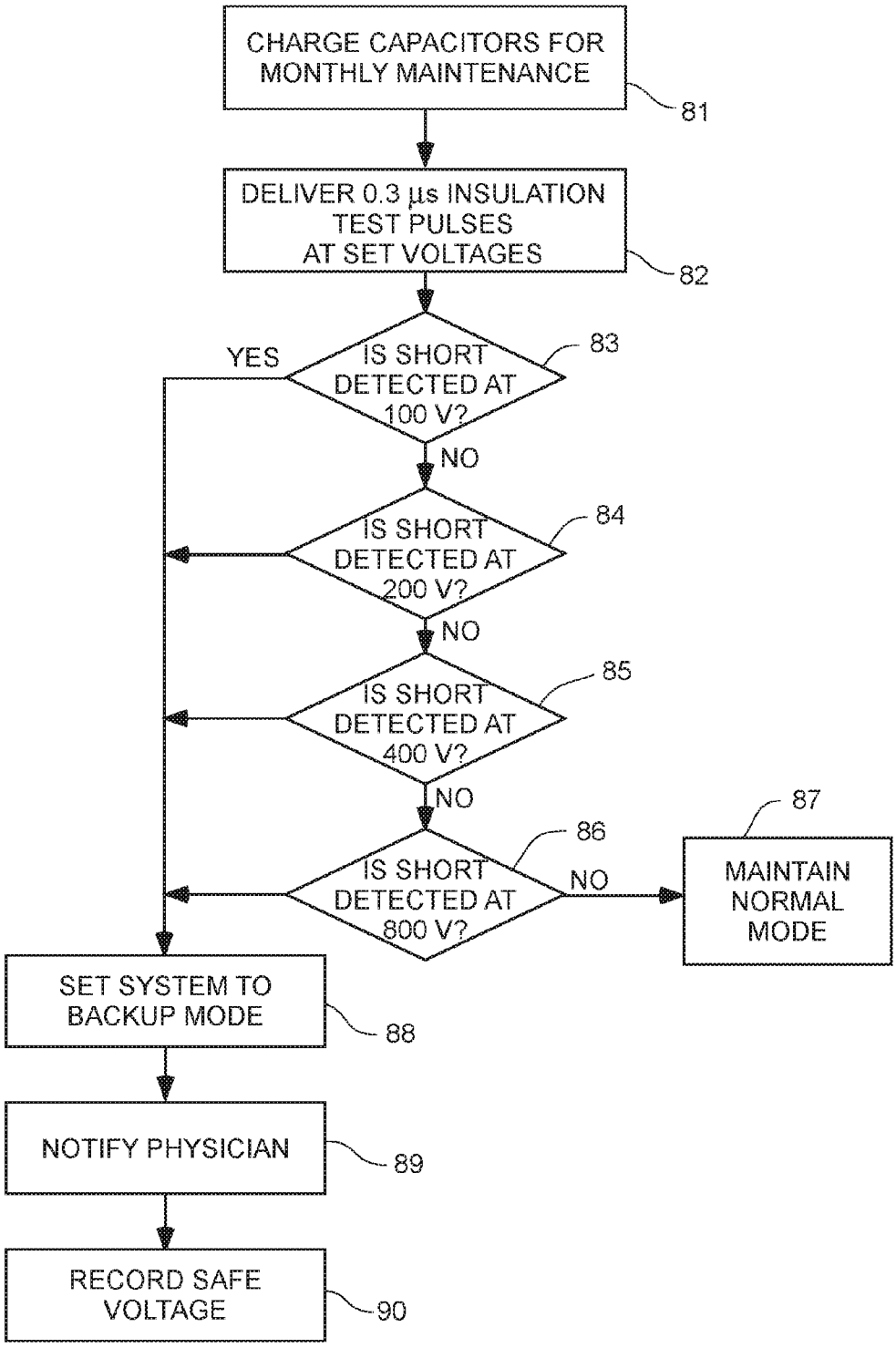

PERFORM DAILY LOW-VOLTAGE INSULATION TEST
72
IS SHORT DETECTED?
73
YES
NO
SET SYSTEM TO BACKUP MODE
74
NOTIFY PHYSICIAN
75
PERFORM MONTHLY HIGH-VOLTAGE INSULATION TEST
76

Fig. 6


CHARGE CAPACITORS FOR MONTHLY MAINTENANCE
81
DELIVER 0.3 µs INSULATION TEST PULSES AT SET VOLTAGES
82
IS SHORT DETECTED AT 100 V?
83
YES
NO
IS SHORT DETECTED AT 200 V?
84
NO
IS SHORT DETECTED AT 400 V?
85
NO
IS SHORT DETECTED AT 800 V?
86
NO
MAINTAIN NORMAL MODE
87
SET SYSTEM TO BACKUP MODE
88
NOTIFY PHYSICIAN
89
RECORD SAFE VOLTAGE
90

METHOD FOR DETECTING AND TREATING INSULATION LEAD-TO-HOUSING FAILURES

RELATED APPLICATION

This application is a continuation of application Ser. No. 13/843,145 filed Mar. 15, 2013, which claims the benefit of U.S. Provisional Application No. 61/689,191 filed Jun. 1, 2012, each of which is hereby fully incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates, generally, to scientific and medical methods. More particularly, the invention relates to methods for diagnosis of conductor anomalies. Most particularly, the invention relates to a method for diagnosis of conductor anomalies, such as insulation failures resulting in the shorting of a defibrillation pathway or circuit, in an implantable medical device, such as an implantable cardioverter defibrillator (ICD). Shorted defibrillation pathways are detected by measuring the impedance of the individual defibrillation pathways. If a short is identified, one electrode from the defibrillation circuit is excluded thus delivering defibrillation current only between functioning defibrillation electrodes.

BACKGROUND

The long-term reliability and safety of implantable cardiac leads is a significant issue. Anomalies of conductors in implantable medical devices constitute a major cause of morbidity. Representative examples of such medical devices include, but are not limited to, pacemakers, vagal nerve stimulators, pain stimulators, neurostimulators, and implantable cardioverter defibrillators (ICDs). For example, early diagnosis of ICD lead conductor anomalies is important to reduce morbidity and/or mortality from loss of pacing, inappropriate ICD shocks, and/or ineffective treatment of ventricular tachycardia or fibrillation (ventricular fibrillation). The early diagnosis of conductor anomalies for implantable cardiac leads is a critically important step in reducing these issues and making ICDs safer.

Multilumen ICD defibrillation electrodes or leads include one or more high-voltage conductors and one or more pace-sense conductors. The leads can be implanted as subcutaneous or intravascular leads. Insulation failures have been known to result in a functional failure of the corresponding conductor. Functional failure of a pace-sense conductor may result in symptoms caused by loss of pacing functions for bradycardia, cardiac resynchronization, or antitachycardia pacing. Functional failure of a high-voltage conductor may result in fatal failure of cardioversion or defibrillation.

Thus, one major goal is high sensitivity of diagnosis: identification of lead insulation failures at the subclinical stage, before they present as a clinical problem. A second major goal is high specificity: a false positive provisional clinical diagnosis of lead insulation failure may trigger patient anxiety and lead to potentially avoidable diagnostic testing. A false positive clinical diagnosis of insulation failure results in unnecessary lead replacement, with corresponding expense and surgical risk. Any clinical method for detecting conductor anomalies in implanted leads must make measurements while the conductor and lead are in the body.

In addition to limited sensitivity, present methods for diagnosing lead conductor anomalies have limited specificity resulting in false positive diagnostics. Evaluation of false positive diagnostics adds cost and work to medical care and may contribute to patient anxiety. If a false-positive diagnostic is not diagnosed correctly, patients may be subject to unnecessary surgical lead replacement with its corresponding risks. In the only report on this subject, 23% of leads extracted for the clinical diagnosis of lead fracture tested normally after explant.

Insulation failures occur most commonly at three regions along the course of a pacemaker or ICD lead. The first region is within the pocket, caused either by abrasion of the lead insulation by pressure from the housing ("CAN") of the pulse generator or twisting of the lead within the pocket. The second region is that between the clavicle and first rib, where the lead is subject to "clavicular crush." The third region is the intracardiac region between or under the shock coils. This third region is a particularly common site of insulation failure for the St. Jude Riata® lead which is subject to "inside-out" insulation failure due to motion of the internal cables relative to the outer insulation. In this case, inside-out abrasion of the cable to the right-ventricular shock coil may abrade against the proximal (superior vena cava) shock coil, resulting in a short circuit within the lead.

Most commonly, insulation failures of ICD defibrillation leads within the pocket can result in abrasion of the insulation around the conductor of the right-ventricular defibrillation coil (coil-CAN abrasion). This abrasion results in a short circuit between the CAN electrode and the right ventricular defibrillation coil. This short circuit prevents defibrillation current from reaching the heart in the event of life threatening ventricular tachycardia or fibrillation. In the case where the shock is delivered, extremely high current flowing through the shorted output circuit of the ICD may irrevocably damage the generator's components. Thus, many modern ICDs contain circuits to protect the ICD against shorted high voltage outputs by aborting the shock if the current in the output circuit is sufficiently high during a shock. However, even though such protective circuitry prevents damage to the generator, it also detrimentally withholds potentially lifesaving therapy from the patient.

Existing technology for diagnosis of conductor anomalies in an ICD lead is believed to have significant limitations and shortcomings. What is desired is a method that could analyze and identify implantable cardiac lead conductor anomalies at the subclinical stage, before they present as a clinical problem, and do so with a high sensitivity and specificity that minimizes false positives for implantable cardiac lead conductor anomalies. In particular, a method for timely and accurate diagnosis of insulation failures of ICD defibrillation leads within the pocket that results in a short circuit between the CAN electrode and the right-ventricular defibrillation coil is needed.

SUMMARY OF THE INVENTION

The disclosed method relates to the diagnosis of conductor anomalies, such as an insulation failure resulting in a short circuit, in an implantable medical device, such as an implantable cardioverter defibrillator (ICD). In various embodiments, a method determines if a specific defibrillation pathway is shorted, and if such a short is present, excludes the one electrode from the defibrillation circuit, delivering defibrillation current only between functioning defibrillation electrodes.

One embodiment provides protection against a short in the right ventricular coil-CAN defibrillation pathway of a pectoral, transvenous ICD with a dual-coil defibrillation lead. If a short caused by an in-pocket abrasion is present, this embodiment excludes the CAN from the defibrillation circuit, delivering defibrillation current only between the right ventricular and superior vena cava defibrillation coils. Determination that the defibrillation pathway is shorted may be made by conventional low current measurements or delivery of high current extremely short test pulses. Embodiments are described that perform testing to determine if a specific defibrillation pathway or conductor forms a short circuit with the CAN. Determination that the defibrillation pathway is shorted may be made by conventional low current measurements or delivery of high current extremely short test pulses.

An embodiment is disclosed of a basic method for detecting a short between the CAN and the RV conductor. A low voltage insulation integrity test is performed between the RV conductor and the CAN. If a short is detected then the system is set into "backup" mode meaning that the RV conductor **23** that is shorted is excluded from the defibrillation circuit and defibrillation current is only delivered between functioning defibrillation electrodes. Notification is transmitted to the physician or patient. If a short is not detected, then a high voltage insulation test is performed on a periodic basis. In one embodiment, the high voltage insulation test could be performed along with the regular capacitor/battery maintenance test.

Another embodiment is disclosed of a high voltage insulation integrity test method for detecting a short between the CAN and an RV conductor. Extremely short pulses, most generally biphasic to minimize sensation, are delivered between the RV conductor and the CAN. The test pulse in the current embodiments is a short "sliver" pulse.

A high voltage short is defined by a sufficient deviation from the range of normal. For example, a short can be defined by the presence of: i) an impedance of <20Ω; ii) a high voltage impedance <50% of the corresponding impedance measured with low voltage pulses, indicating voltage dependent dielectric breakdown; or iii) a ratio of high voltage to low voltage impedance significantly less than the average of the corresponding values for the last three measurements. The preferable 20 Ω cutoff value could be set to any value from 0 Ω to 30 Ω with a better range being 5 Ω to 25Ω. The percentage cutoff can be 20% to 60% or alternatively a drop of >30 Ω from the low voltage value.

In one embodiment, when the capacitors are charged for regular maintenance, a plurality of sliver test pulses are delivered until the capacitor voltage attains 100 V. If a short is not detected then sliver test pulses are delivered in increasing 100V steps until the capacitor voltage attains 800 V with a determination made at each step as whether a short is detected at a particular voltage. If a short has not been detected at 800 V, the ICD is maintained in its normal mode of defibrillation.

If a short is detected at any one of the stepped test modes then the system is set to "backup" mode meaning that the shorted conductor is excluded from the defibrillation circuit and defibrillation current is only delivered between functioning defibrillation electrodes. Notification of a short circuit is transmitted to the physician or patient. In another embodiment, where a short was detected at 100 V, a "safe" voltage of 0 V is recorded as a maximum voltage for that defibrillator electrode path. If a short was detected at a higher step level, for example, 200 V, then a "safe" voltage of the previous step load, for example, 100 V is recorded as a maximum voltage for that defibrillator electrode path.

The 100 V stepped process provides a better resolution of the "safe" voltage that the insulation can withstand from a partial insulation abrasion. In other embodiments, testing may also be performed in an alternative order of pulse strength, for example, with the 800 V pulse delivered first then stepping down to 100 V, or randomly testing the various predetermined step levels.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be more completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. **1** depicts the backup defibrillation mode method.

FIG. **2** depicts one example of a multilumen ICD lead.

FIG. **3** illustrates regions within the human body associated with the implantation of an ICD and associated leads.

FIG. **4** shows an implantable medical device in which an embodiment of the present invention may be practiced. It shows an ICD pulse generator connected to a patient's heart via a transvenous cardiac lead used for pacing and defibrillation further illustrating a short from the RV conductor to the ICD housing.

FIG. **5** is a flowchart depicting the basic method of detecting a short between the ICD housing and the RV conductor.

FIG. **6** is a flowchart depicting the method of detecting a short using the high voltage insulation integrity test.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

Disclosed is a method for diagnosis of conductor anomalies, such as insulation failures resulting in the shorting of a defibrillation pathway, in an implantable medical device, such as an implantable cardioverter defibrillator (ICD). Shorted defibrillation pathways are detected by measuring the impedance of the individual defibrillation pathways. If a short is identified, one electrode from the defibrillation circuit is excluded thus delivering defibrillation current only between functioning defibrillation electrodes.

Modern ICDs routinely deliver low voltage, on the order of 5 volts to 15 volts, pulses or switched AC pulse trains to assess electrical integrity of the high voltage shock pathway. However, clinical case reports indicate that life threatening insulation failures may not be detected by these low voltage measurements. Patients have died when shocks have short circuited, preventing the shock energy from reaching the heart and defibrillating ventricular fibrillation.

FIG. **1** depicts a backup defibrillation mode method which is a method of switching out the ICD housing in the event that a short is detected during the shock as disclosed in U.S. Pat. No. 7,747,320 to Kroll. However, this method typically involves a maximum voltage shock which may have enough energy to "spot weld" the exposed conductor to the housing and to ablate additional insulation which will exacerbate the

insulation failure. In addition, the backup of using only the right ventricular (RV) to superior vena cava (SVC) coil-to-coil defibrillation shock is frequently unsuccessful and hence may result in a patient death. Therefore, a method of predicting such high voltage insulation failure, well in advance of a needed defibrillation, is needed.

FIG. **2** illustrates one example of an implantable cardiac lead **10**. The lead **10** is comprised of a lumen **12** and center inner pacing coil **14** surrounded by PTFE insulation **16**, a plurality of lumens **18** each containing at least one conductor **20** with each conductor **20** surrounded by ETFE insulation **22**, an outer insulating layer **24**, and a silicone insulation **26** disposed between the lumen **12** and the outer insulating layer **24**. The conductors **20** include a sense conductor **21**, a high voltage RV conductor **23**, and a high voltage SVC conductor **25**. The plurality of lumens **18** are disposed in the silicone insulation **26**. The conductors **20** carry electric current to the pace-sense electrodes **66**, **68**, high voltage RV coil **64** and high voltage SVC coil **62** (FIG. **4**).

As discussed above, and shown in FIG. **3**, insulation failures most commonly occur at three regions along the course of an ICD lead **10**. The first region **32**, and the one at issue in this disclosure, is within the pocket, caused either by abrasion of the lead **10** insulation **24** by pressure from the housing ("CAN") **44** of the pulse generator or twisting of the lead **10** within the pocket. The second region **34** is that between the clavicle and first rib, where the lead **10** is subject to "clavicular crush." The third region **36** is the intracardiac region near the tricuspid valve.

FIG. **4** depicts on ICD **42** implanted in the chest of a patient. The ICD **42** has an outer housing **44**, commonly referred to as a "CAN," inner circuitry **46** and a battery **48**. Connection is made to the heart **50** via the lead **10**. The lead **10** can have an optional proximal defibrillation coil **52** which is near the superior vena cava and is commonly referred to as the SVC coil **52**. The lead **10** also has a distal defibrillation coil **54** which is commonly referred to as the right ventricular coil or RV coil **54**. Also shown is the optional "ring" pacing-sensing electrode **56**. Located at the distal end of the lead **10** is the "tip" pacing-sensing electrode **58**.

The outer insulating layer **24** of the leads **10** is generally a polymer such as silicone, polyurethane, or a copolymer of silicone and polyurethane. Stress on the insulation **24** from outside-in abrasion from contact with the CAN **44**, or inside-out abrasion from movement of the cables within the lead **10** may result in insulation **24** breaches or failures. In addition, the insulation **24** can fail due to chemical reactions such as metal-ion oxidation.

FIG. **4** depicts a lead **10** insulation **24** failure at location **60**. In this embodiment, the insulation **24** has been abraded so that a short circuit **62** has been formed between the CAN **44** and the RV conductor **23**.

Embodiments are described that perform testing to determine if a specific defibrillation pathway or conductor forms a short circuit with the CAN **44**. If such a short **62** is present, the one shorted electrode is removed from the defibrillation circuit so that defibrillation current is delivered only between functioning defibrillation electrodes. One embodiment provides protection against a short in the right ventricular coil-CAN defibrillation pathway of a pectoral, transvenous ICD with a dual-coil defibrillation lead. For example, if a short caused by an in-pocket **32** abrasion is present, the invention excludes the CAN **44** from the defibrillation circuit, delivering defibrillation current only between the right ventricular **54** and superior vena cava **52** defibrillation coils. Determination that the defibrillation pathway is shorted may be made by conventional low current measurements or delivery of high current extremely short test pulses.

FIG. **5** depicts an embodiment of a basic method for detecting a short between the CAN **44** and the RV conductor **23**. A low voltage insulation integrity test **72** is performed between the RV conductor **23** and the CAN **44**. This test **72** can be done on a daily basis. However, the frequency of testing **72** can be modified as needed. If a short is detected **73** then the system is set into "backup" mode **74** meaning that the RV conductor **23** that is shorted is excluded from the defibrillation circuit and defibrillation current is only delivered between functioning defibrillation electrodes. Notification is transmitted to the physician **75** by, for example, remote wireless telemetry. In an embodiment, the physician or patient can be notified via a vibratory or auditory alert. If a short is not detected, then a high voltage insulation test (FIG. **6**) is performed on a periodic basis **76** that is longer than the daily basis for test **72**. In one embodiment, the high voltage insulation test could be performed along with the regular capacitor/battery maintenance test. The high voltage insulation test can be performed every two weeks up to once every 6 months. However, a monthly test is more likely to detect changes in the integrity of the circuit. The frequency of testing may be influenced by whether or not the lead in use is known to be particularly prone to insulation failure.

FIG. **6** depicts an embodiment of a high voltage insulation integrity test method for detecting a short between the CAN **44** and an RV conductor **23**. Extremely short pulses, most generally biphasic to minimize sensation, are delivered according to the teachings of U.S. Pat. No. 8,352,033, issued Jan. 8, 2013, which relevant sections are hereby incorporated by reference. However, refinement is provided herein in that the test pulse in the current embodiments is a short "sliver" pulse of 0.3 μs with an acceptable range of 0.1 μsec to 1.0 μsec in duration. Pulse durations of 1.0 μsec to 2.0 μsec are also usable but they introduce more patient sensation. Pulses may be delivered between the RV conductor **23** and the CAN **44**, or between other pairs of conducting defibrillator electrodes.

A high voltage short is defined by a sufficient deviation from the range of normal. For example, a short can be defined by the presence of: i) an impedance of <20Ω; ii) a high voltage impedance <50% of the corresponding impedance measured with low voltage pulses, indicating voltage dependent dielectric breakdown; or iii) a ratio of high voltage to low voltage impedance significantly less than the average of the corresponding values for the last three measurements. The preferable 20 Ω cutoff value could be set to any value from 0 Ω to 30 Ω with a better range being 5 Ω to 25Ω. The percentage cutoff can be 20% to 60% or alternatively a drop of >30 Ω from the low voltage value.

FIG. **6** involves charging the capacitors for regular maintenance **81**, generally monthly. However, maintenance can be performed at any time interval as determined by the physician. Sliver test pulses **82** are delivered, as described above, until the capacitor voltage attains 100 V. Determination is made as to whether a short is detected at 100 V **83**. If a short is not detected then sliver test pulses are delivered until the capacitor voltage attains 200 V and a determination is made as to whether a short is detected at this voltage **84**. If a short is not detected then sliver test pulses are delivered until the capacitor voltage attains 400 V and a determination is made as to whether a short is detected at this voltage **85**. If a short is not detected then sliver test pulses are delivered until the capacitor voltage attains 800 V and a determination is made as to whether a short is detected at this voltage **86**.

At this point, if a short has not been detected, the ICD is maintained in its normal mode **87** of defibrillation.

If a short is detected at any one of the test modes **83**, **84**, **85**, **86** then the system is set to "backup" mode **88** meaning that the shorted conductor **23** is excluded from the defibrillation circuit and defibrillation current is only delivered between functioning defibrillation electrodes. Notification is transmitted to the physician **89** by, for example, remote wireless telemetry. In an embodiment, the physician or patient can be notified via a vibratory or auditory alert. In another embodiment, where a short was detected at 100 V, a "safe" voltage of 0 V is recorded **90** as a maximum voltage for that defibrillator electrode path. If a short was detected at a higher step level, for example, 200 V, then a "safe" voltage of the previous step load, for example, 100 V is recorded **90** as a maximum voltage for that defibrillator electrode path.

For simplicity, the voltage steps are shown as 100, 200, 400, and 800 volts in FIG. **6**. It is contemplated that the high voltage insulation integrity test can be performed in 100 V steps up to the maximum output voltage. This 100 V stepped process provides a better resolution of the "safe" voltage that the insulation can withstand from a partial insulation abrasion. Alternatively, other incremental values may be utilized, e.g., 50 V and 150V. Testing may also be performed in an alternative order of pulse strength, for example, with the 800 V pulse delivered first then stepping down to 100 V.

Note that this method of FIG. **6** can be applied after ventricular fibrillation has been detected. It is anticipated that the high voltage insulation test will be performed during regular battery/capacitor maintenance, and during capacitor charging after ventricular fibrillation has been detected.

In one embodiment, the high voltage insulation test can be performed up to 400 V every month and up to 800 V every 6 months. The advantage of alternating testing voltages is the reduction in energy consumption as the 400 V shock requires <25% of the charging energy of the 800 V shock.

The values noted above are example embodiments and should not be read as limiting the scope of this invention. Those skilled in the art will recognize that the above values may be adjusted to practice the invention as necessary depending on the electrode implantable cardiac lead technology used and the physical characteristics of the patient.

While the present invention has been described with reference to certain embodiments, those skilled in the art should appreciate that they can readily use the disclosed conception and specific embodiments as a basis for designing or modifying other structures for carrying out the same purposes of the present invention without departing from the spirit and scope of the invention as defined by the appended claims.

The following patents and applications, the disclosures of which are incorporated by reference in this case (other than claims and express definitions), are prior art attempts by common inventors to solve the problem at issue: U.S. Pat. No. 8,352,033 ('033) to Kroll, issued Jan. 8, 2013; U.S. patent application Ser. No. 13/735,599 to Kroll, filed on Jan. 7, 2013 which is a continuation of '033; and U.S. patent application Ser. No. 12/868,056 to Swerdlow, filed on Aug. 25, 2010.

The following provisional applications, the disclosures of which are incorporated by reference in this case (other than claims and express definitions), are related to each other: U.S. Patent Application 61/689,191 to Kroll and Swerdlow, filed on Jun. 1, 2012; U.S. Patent Application 61/689,189 to Kroll and Swerdlow, filed on Jun. 1, 2012; and U.S. Patent Application 61/733,713 to Kroll and Swerdlow, filed on Dec. 5, 2012.

The invention claimed is:

1. An automated method of periodically monitoring for a potential short circuit in an implantable defibrillation system comprising:

causing the implantable defibrillation system to perform the steps of:

periodically forming a defibrillation pathway among at least two of an implantable cardioverter defibrillator generator housing (CAN) electrode a superior vena cava (SVC) electrode and a right ventricle (RV) electrode;

measuring an impedance of the defibrillation pathway using a high voltage, short duration pulse;

determining if the impedance is within a low impedance range indicative of a short circuit;

wherein periodically forming the defibrillation pathway is scheduled on an approximately monthly schedule;

wherein measuring the impedance of the defibrillation pathway uses a high current, short duration, test pulse at successively increasing voltages; and

in response to determining that the impedance is in the low impedance range, altering a configuration for delivery of a defibrillation shock into the defibrillation pathway to restrict use of a conductor associated with the defibrillation pathway that has low impedance range.

2. The automated method of claim **1**, wherein a maximum voltage for the test pulse is about 400 V.

3. The automated method of claim **2**, further comprising altering delivery of the defibrillation shock by lowering the voltage of the defibrillation shock to the maximum safe voltage for the conductor associated with the defibrillation pathway that has low impedance range.

4. The automated method of claim **1**, wherein a maximum voltage for the test pulse is about 800 V.

5. The automated method of claim **1**, wherein a first maximum voltage for the test pulse is set for every month and a second maximum voltage is set for every six months.

6. An automated method of periodically monitoring for a potential short circuit in an implantable defibrillation system comprising:

causing the implantable defibrillation system to perform the steps of:

periodically forming a defibrillation pathway among at least two of an implantable cardioverter defibrillator generator housing (CAN) electrode a superior vena cava (SVC) electrode and a right ventricle (RV) electrode;

measuring an impedance of the defibrillation pathway using a high voltage, short duration pulse;

determining if the impedance is within a low impedance range indicative of a short circuit:

wherein measuring the impedance of the defibrillation pathway uses a high current, short duration test pulse at successively increasing voltages concurrently with regular capacitor charging maintenance of the implantable defibrillation system; and

in response to determining that the impedance is in the low impedance range, altering a configuration for delivery of a defibrillation shock into the defibrillation pathway to restrict use of a conductor associated with the defibrillation pathway that has a low impedance range.

7. An automated method of periodically monitoring for a potential short circuit in an implantable defibrillation system comprising:

causing the implantable defibrillation system to perform the steps of:

periodically forming a defibrillation pathway among at least two of an implantable cardioverter defibrillator generator housing (CAN) electrode a superior vena cava (SVC) electrode and a right ventricle (RV) electrode;

measuring an impedance of the defibrillation pathway using a high voltage, short duration pulse;

determining if the impedance is within a low impedance range indicative of a short circuit;

in response to determining that the impedance is in the low impedance range, altering a configuration for delivery of a defibrillation shock into the defibrillation pathway to restrict use of a conductor associated with the defibrillation pathway that has a low impedance range; and

wherein measuring the impedance of the defibrillation pathway uses a high current, short duration test pulse at successively increasing voltages, and wherein the automated method further comprises:

recording, for the defibrillation pathway, a maximum safe voltage that corresponds to the highest voltage at which the impedance was not in the low impedance range.

8. The automated method of claim 7, wherein the low impedance range is defined by an impedance of 0 to 30Ω.

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